UNCLASSIFIED

TITANIUM SHEET ROLLING PROGRAM

FOR

Ti-8Al-1Mo-1V, Ti-5Al-5Sn-5Zr, and Ti-7Al-12Zr

NINTH BIMONTHLY REPORT

Covers period 1 November - 31 December 1960

Prepared Under Navy, Bureau Of Naval Weapons' Contract NOas-59-6227-c

7 July 1961

Titanium Metals Corporation of America
TECHNICAL DEPARTMENT
TORONTO, OHIO

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Prepared by:
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TITANIUM METALS CORPORATION OF AMERICA
TECHNICAL DEPARTMENT
Toronto, Ohio

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ABSTRACT

In this report period, properties were obtained on 30 pilot sheets of Ti-8Al-1Mo-1V, which indicated that mill annealing for four hours at 1450F provides sub-standard creep resistance at 1000F. Additional laboratory studies showed that a much better combination of properties is achieved by mill annealing for 8 hours at 1450F. The 92 remaining sheets from the five 1600-pound heats were finish rolled from 1800F and will be mill annealed at 1450F (8 hrs).

Preliminary evaluation of the initial sheets of Ti-5Al-5Sn-5Zr and Ti-7Al 12Zr was completed including notch and standard tensile properties at several different temperatures and 1000F creep-stability studies. An optimum finish rolling temperature of 1750F was established for both alloys, but additional studies are required before the optimum final annealing temperature can be selected. The balance of material from the first ingot of each composition was scheduled for sheet processing and bars for 29 sheets were rolled to an intermediate stage, conditioned, and vacuum annealed ready for finish rolling from 1750F. Melting of three 1700-pound ingots of each of Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr was scheduled for the production phase of the contract.

NINTH BIMONTHLY REPORT

TITANIUM SHEET ROLLING PROGRAM FOR Ti-8Al-1Mo-1V, Ti-5Al-5Sn-5Zr, and Ti-7Al-12Zr

INTRODUCTION

The purpose of Contract NOas 59-6227-c is to establish optimum sheet processing procedures for three advanced alpha or essentially all-alpha titanium alloys; Ti-8Al-1Mo-1V, Ti-5Al-5Sn-5Zr, and Ti-7Al-12Zr; and to produce substantial quantities of sheet from each of the three for evaluation by Department of Defense contractors.

During previous report periods, one 3500-pound ingot of Ti-8Al-1Mo-1V was processed to sheet and the optimum finish rolling and annealing temperatures were established. In the production phase of the contract, processing of five 1600-pound ingots of Ti-8Al-1Mo-1V was initiated with a pilot group of sheets being finished first to verify the selected conditions and procedures. Initial sheets were rolled from one 1700-pound ingot of each of Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr to determine optimum finish rolling and annealing temperatures. Thorough evaluation of these first sheets is in progress; preliminary results indicated that better properties are achieved with the lower rolling temperatures.

In this, the ninth report period covering 1 November - 31 December 1960, properties were obtained on the pilot group of 30 Ti-8Al-1Mo-1V sheets. The balance of 92 sheets from the five heats of Ti-8Al-1Mo-1V were finish rolled. Unnotched elevated-temperature and subzero temperature notch-tensile and initial 1000F creep-stability properties were obtained on the initial sheets of Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr, permitting the selection of an optimum finish rolling temperature. Sheet processing the balance of the slab material from the first two ingots of Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr was scheduled and melting of six 1700-pound heats of both alloys was initiated for the production phase of the contract.

PROPERTIES OF Ti-8Al-1Mo-1V SHEETS

As indicated in the Eighth Bimonthly Report(1), a pilot group of 30 Ti-8Al-1Mo-1V sheets from the five 1600-pound ingots was finish rolled from 1800F to verify the previously-established rolling and, particularly, mill annealing cycles. In this period the 30 sheets were mill annealed at 1450F for 4 hours, ground, pickled, and tested. Additional test strips were also cut from a few of the sheets for creep-stability evaluation. Results of these tests are described in the two sections to follow.

Tensile and Bend Properties of 30 Pilot Sheets

In routine mill testing one longitudinal and one transverse strip were sheared from the sides and ends of each of the 30 sheets and tensile and bend tests were performed on each at room temperature. The resultant properties are listed in Table 1 together with averages and ranges, which show several items of interest. First, all four gages except the 0.090in exhibited reverse directionality, with this effect being considerably more pronounced in the 0.040 and 0.062in sheets. Reviewing the three-stage cross rolling procedures used on these sheets showed that greater percentages of reduction were taken in the second stage compared to the third, although the differences were much less for the 0.020 and 0.090in gages than for the 0.040 and 0.062in material. Thus, there was a direct correlation between the reverse directionality and the second and third stage of the cross rolling schedule.

Second, the strength level of all 30 sheets was generally about 10 Ksi higher than predicted from the laboratory treated samples described in the Eighth Bimonthly Report(1). The laboratory annealing cycle was programmed such that it simulated a slowly heated-slowly cooled load in a production furnace. Unfortunately, the simulated cycle was patterned after an average size load of sheets, whereas the 30 sheets that were mill annealed constituted a very small furnace load. Therefore, although the 30 sheets were held at 1450F for 4 hours, they heated and cooled more rapidly than a larger load of sheets and, consequently, were in the annealing range (above1350-1400F) for a considerably shorter time. To compensate for the fact that small furnace

TABLE 1 ROOM-TEMPERATURE TENSILE AND BEND PROPERTIES OF 30 PILOT SHEETS OF Ti-8Al-1Mo-1V (Finish rolled from 1800F and mill annealed at 1450F - 4 hrs)

Sheet No.	Dir	UTS, Ksi	YS(0.2%), Ksi	Elong (2"), %	Min. Bend Radius, T	H_2 ppm
0.020", V-1553B, Test A-5514						
#1	L	157.8	154.7	17.0	3.0	
	T	158.0	151.9	12.5	"	
#2	L	160.0	149.1	17.0	"	70
	T	157.7	145.1	12.5	"	
#3	L	156.8	150.0	14.0	"	
	T	153.5	147.0	10.5	"	
#4	L	160.5	150.6	17.5	"	
	T	157.4	149.2	8.0(1)	"	
#5	L	155.5	147.2	15.0	"	80
	T	154.8	146.3	12.5	"	
#6	L	158.1	148.7	12.5	"	
	T	157.1	149.7	12.0	"	
#7	L	162.6	151.8	14.5	"	
	T	153.1	144.7	9.5(1)	"	
#8	L	161.0	151.9	14.5	"	
	T	157.2	148.8	14.0	"	
#9	L	157.1	150.3	13.5	"	
	T	157.1	149.5	14.0	3.7	
Av	L	158.8	150.5	15.1	3.0	
Range	L	155.5-162.6	147.2-154.7	12.5-17.0	---	
Av	T	156.2	148.0	12.6	3.0	
Range	T	153.1-158.0	144.7-151.9	10.5-14.0	---	
0.040", V-1554M, Test A-5491						
#1	L	154.6	146.2	14.5	3.0	
	T	149.2	143.0	12.0	3.0	
#2	L	160.7	152.1	14.5(1)	3.3	80
	T	148.9	144.3	13.0	3.2	
#3	L	157.8	145.7	16.0(1)	3.2	
	T	149.7	141.1	14.5	3.1	
#4	L	165.5	153.3	15.0(1)	2.8	
	T	148.8	145.4	12.5	2.9	
#5	L	160.3	150.0	18.0(1)	2.8	
	T	148.1	142.1	16.0	3.1	
#6	L	162.9	149.7	16.0	2.5	60
	T	144.3	139.5	15.0	2.5	
#7	L	161.2	150.4	17.0	3.1	
	T	146.2	140.0	13.0	2.5	

(continued)

TABLE 1 (continued)

Sheet No.	Dir*	UTS, Ksi	YS(0.2%), Ksi	Elong(2") %	Min. Bend Radius, T	H_2 ppm
0.040", Test A-5[illegible]29, V-1554M						
#1	L	165.4	153.6	17.5	3.0	110
	T	155.3	147.2	13.5	"	
#2	L	164.1	153.8	8.5(1)	"	90
	T	153.4	146.0	12.0	"	
Av	L	161.4	150.5	16.1	3.0	
Range	L	154.6-165.5	145.7-153.8	14.5-18.0	2.5-3.3	
Av	T	149.3	143.2	13.5	2.9	
Range	T.	144.3-155.3	139.5-147.2	12.0-16.0	2.5-3.2	
0.062", Test A-5472, V-1555B						
#1	L	158.8	148.9	15.5	2.4	
	T	152.2	145.8	12.5	"	
#2	L	160.5	151.5	15.5	"	
	T	150.8	146.2	15.0	"	
#3	L	163.7	153.5	15.5	"	100
	T	149.5	143.6	14.5	"	
#4	L	160.3	151.3	15.5	3.0	
	T	149.6	143.9	14.5	3.0	
#5	L	162.0	150.7	16.5(1)	2.4	
	T	157.7	144.2	13.0	"	
#6	L	161.4	150.6	15.5	"	110
	T	155.2	144.7	13.0	"	
Av	L	161.1	151.1	15.7	2.5	
Range	L	158.8-163.7	148.9-153.5	15.5-16.5	2.4-3.0	
Av	T	152.5	144.7	13.8	2.5	
Range	T	149.5-157.7	143.6-145.8	12.5-15.0	2.4-3.0	
0.090", Test A-5473, V-1555M						
#1	L	156.2	146.5	16.5	2.5	
	T	146.0	140.8	13.5	2.8	
#2	L	152.4	143.5	11.5	2.5	50
	T	160.4	149.5	14.0	2.5	
#3	L	151.0	147.3	12.0	2.5	
	T	146.9	141.0	13.5	2.8	
#4	L	153.7	146.0	14.0	2.5	
	T	150.3	144.1	15.0	2.5	
#5	L	154.0	145.5	12.0	2.5	
	T	165.4	152.8	16.5	2.8	
#6	L	150.1	142.0	12.5	2.5	50
	T	159.8	148.0	12.0	2.8	

TABLE 1 (continued)

Sheet No.	Dir	UTS, Ksi	YS(0.2%), Ksi	Elong(2"), %	Min. Bend Radius, T	H_2, ppm
Av	L	152.9	145.1	13.3	2.5	
Range	L	150.1-156.2	142.0-147.3	12.0-16.5	---	
Av	T	154.8	146.0	14.1	2.7	
Range	T	146.0-165.4	140.8-152.8	12.0-16.5	2.5-2.8	

(1) Broke at end of gage length.

loads of Ti-8Al-1Mo-1V sheet would probably be encountered at least occasionally in production processing, it was concluded that 1450F for 8 hours would be a much improved annealing cycle, which would tend to compensate for different heating and cooling rates in small and large furnace loads.

Even though the unexpected reverse directionality and higher strengths were obtained, the ductility of the sheets was at a high level. Of particular interest was the excellent bendability with the minimum bend radius of all 30 sheets at 3.7 T or less, and this higher value was observed in just one sheet of 0.020in. Except for this one value, all bend radii were 3.3 T or less with nearly half of the sheets passing a radius less than 3.0 T. Therefore, by adjusting the cross rolling schedule and mill annealing future sheets of Ti-8Al-1Mo-1V at 1450F for 8 hours, excellent properties should be achieved.

Creep-Stability of Ti-8Al-1Mo-1V Pilot Sheets

Strips were sheared from one sheet of each of the three heavier gages in the pilot group of 30 sheets and creep-stability specimens were prepared and exposed to 1000F - 25 Ksi - 150 hours. Results of these tests, which are listed in Table 2, show that the creep deformation was generally almost twice that obtained on corresponding transverse strips of hot rolled sheets which had been laboratory annealed at 1450F (4 hrs)[1]. In addition, the strength of the mill annealed material was also 5 - 10 Ksi higher than laboratory treated samples, an observation discussed in the previous section. Except for the 0.062in specimens, the elongation values after exposure were quite low. Reasons for this are not fully known, although the under-annealing obtained in the 4-hour mill cycle at 1450F may have been a contributing factor. Also, specimens breaking at the end of the gage length and at the point where the thermocouple supporting tie-wire contacted the sample surface during creep exposure were the major reasons for low exposed elongation.

Comparing these creep data (Table 2) with the results of laboratory annealed annealed creep-stability samples[1] and referring to the tensile properties listed in Table 1, it was concluded pretty positively that the light load of 30 sheets, which had resulted in a shorter overall mill annealing cycle, was under-annealed and that the time at 1450F should be extended to 8 hours. To confirm this, additional strips from one mill

TABLE 2 - CREEP-STABILITY PROPERTIES OF Ti-8Al-1Mo-1V PILOT SHEETS MILL ANNEALED AT 1450F (4 HRS) * (Finish rolled from 1800F; creep exposure 1000F - 25 Ksi - 150 hrs)

Heat	Sheet Designation	Gage, in	Dir	Heat Treatment	Creep Def, %	UTS, Ksi	YS(0.2%), Ksi	Elong (1"), %
V1554M	S-3261, #9	0.040	L	As Mill Annealed	Not Exp.	169.1	153.9	19
			L	" " "	3.88	155.8	152.3	4
			L	1800F(5 min)AC + 1100F(8 hrs)	Not Exp.	174.2	158.2	18
			L	" + "	1.14	158.3	147.5	2(1)
V1555B	A-5472	0.062	T	As Mill Annealed	Not Exp.	151.1	141.6	13.5
			T	" " "	3.69	155.8	144.7	12
			T	1800F(5 min)AC + 1100F (8 hrs)	Not Exp.	159.2	149.2	13
			T	" + "	1.73	160.5	152.0	12
V1555M	A-5473	0.090	T	As Mill Annealed	Not Exp.	156.5	146.6	15.5
			T	" " "	2.30	152.6	143.4	3(2)
			T	1800F(5 min)AC + 1100F (8 hrs)	Not Exp.	163.4	147.8	16.5
			T	" "	0.95	152.1	144.8	2(1, 2)

(*) Tensile tested at room temperature after creep exposure without surface pickling or conditioning.

(1) Broke at end of gage length.
(2) Broke at point where thermocouple supporting tie-wire contacted the specimen surface.

TABLE 2 - CREEP-STABILITY PROPERTIES OF Ti-8Al-1Mo-1V PILOT SHEETS MILL ANNEALED AT 1450F (4 HRS) * (Finish rolled from 1800F; creep exposure 1000F - 25 Ksi - 150 hrs)

Heat	Sheet Designation	Gage, in	Dir	Heat Treatment	Creep Def, %	UTS, Ksi	YS(0.2%), Ksi	Elong (1"), %
V1554M	S-3261, #9	0.040	L	As Mill Annealed	Not Exp.	169.1	153.9	19
			L	" " "	3.88	155.8	152.3	4
			L	1800F(5 min)AC + 1100F(8 hrs)	Not Exp.	174.2	158.2	18
			L	" + "	1.14	158.3	147.5	2(1)
V1555B	A-5472	0.062	T	As Mill Annealed	Not Exp.	151.1	141.6	13.5
			T	" " "	3.69	155.8	144.7	12
			T	1800F(5 min)AC + 1100F (8 hrs)	Not Exp.	159.2	149.2	13
			T	" + "	1.73	160.5	152.0	12
V1555M	A-5473	0.090	T	As Mill Annealed	Not Exp.	156.5	146.6	15.5
			T	" " "	2.30	152.6	143.4	3(2)
			T	1800F(5 min)AC + 1100F (8 hrs)	Not Exp.	163.4	147.8	16.5
			T	" "	0.95	152.1	144.8	2(1,2)

(*) Tensile tested at room temperature after creep exposure without surface pickling or conditioning.

(1) Broke at end of gage length.
(2) Broke at point where thermocouple supporting tie-wire contacted the specimen surface.

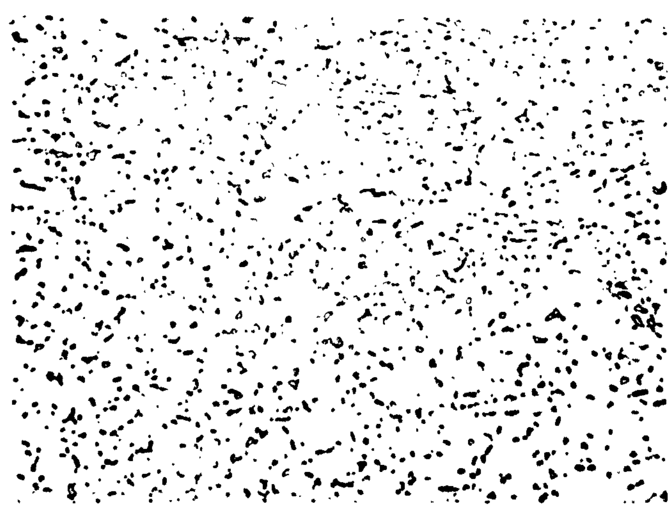
TABLE 3 - ROOM-TEMPERATURE TENSILE AND 1000F CREEP-STABILITY PROPERTIES OF LABORATORY RE-ANNEALED Ti-8Al-1Mo-1V SHEETS * (Originally mill annealed + laboratory annealed at 1450F for 4 hrs; creep exposure 1000F - 25 Ksi - 150 hrs)

Heat	Sheet Designation	Gage, in	Dir	Creep Def, %	UTS, Ksi	YS(0.2%), Ksi	Elong., % (1")	Elong., % (2")
V1553B	A-5514	0.020	L	Not Exp.	152.4	139.3	-	12
			T	"	151.2	142.0	-	12.5
			L	"	150.2	143.3	14	-
			L	2.36	152.8	145.2	7(1)	-
			T	Not Exp.	152.1	144.2	16	-
			T	2.33	151.3	142.2	7(1)	-
V1554M	A-5491, #1	0.040	L	Not Exp.	158.2	142.9	-	12
			T	"	146.0	135.6	-	7.5(1)
			L	"	159.8	146.3	16	-
			L	1.69	151.1	143.8	3	-
			T	Not Exp.	145.2	140.3	10.5	-
			T	1.83	145.2	135.8	5(1)	-
V1555B	A-5472	0.062	L	Not Exp.	160.2	146.9	-	13.5
			T	"	145.7	138.8	-	14
			L	"	161.0	148.4	16	-
			L	2.02	152.7	147.3	3	-
			T	Not Exp.	147.2	140.6	16.5	-
			T	2.12	147.8	139.9	6	-
V1555M	A-5473, #3	0.090	L	Not Exp.	148.8	138.8	-	5
			L	"	151.4	145.0	17	-
			L	1.55	150.6	143.2	5	-

(*) Tensile tested at room temperature after creep exposure without surface pickling or conditioning.
(1) Broke at end of gage length.

X60-137-I2 Kroll Etch 500X

FIGURE 1 Ti-8Al-1Mo-1V, V-1555M, A-5473, 0.090IN, LONGITUDINAL SECTION. AS MILL ANNEALED 1450F (4 HRS).



X61-3-D2 Kroll Etch 500X

FIGURE 2 Ti-8Al-1Mo-1V, V-1555M, A-5473-#3, 0.090IN, LONGITUDINAL SECTION. MILL ANNEALED 1450F (4 HRS) + LABORATORY ANNEALED 1450F (4 HRS) FC TO 1000F.

annealed sheet of each of the four gages in the pilot group of 30 were given the same laboratory annealing treatment as had been used in much of the investigation described in the Eighth Bimonthly Report[1]; i.e., slowly heat to 1450F, hold for 4 hours, and slowly cool to 1000F. This, in effect, provided each strip with a total of 8 hours at 1450F. Creep-stability specimens were prepared and creep exposed at 1000F-25 Ksi - 150 hrs with the results shown in Table 3. Included, also, are unexposed tensile properties from both 1- and 2-inch gage length samples which had received the same laboratory annealing treatment.

Comparing the creep deformation values in Tables 2 and 3, it is seen that a marked improvement in creep resistance was achieved by laboratory re-annealing at 1450F (4 hrs) FC to 1000F. In fact, the creep data compare quite favorably with those obtained earlier on hot rolled-and-laboratory annealed samples[1]. Some of the tensile elongations after creep exposure were lower than expected; again, reasons for this are not readily apparent, but may be partially explained by the large creep elongations which undoubtedly affect tensile ductility.

Metallographic evidence of the difference between 1450F (4 hrs) mill annealed and mill annealed-plus-1450F (4 hrs) laboratory annealed microstructures of 0.090in sheet is depicted in Figures 1 and 2. Indications of under-annealing are shown in Figure 1 by the somewhat elongated stringers of beta particles, which are semi-continuous in nature. The beta particles after additional laboratory annealing at 1450F, as shown in Figure 2, are much more equiaxed, slightly larger in size, and definitely discrete and separate. This latter observation, compared to the stringers of beta particles in Figure 1, no doubt accounts, at least in part, for the improved creep resistance of the sheet represented in Figure 2, since it is an accepted fact that the beta phase possesses inferior creep resistance in alpha-beta titanium alloys.

Using the same heating and cooling rates as for the samples in Table 3, additional tensile specimens from both 1350F (8 hrs) and 1450F (4 hrs) mill annealed sheets were re-annealed in the laboratory for 8 hours at 1450F to determine if any substantial decrease in strength was obtained for this longer time compared to 1450F (4 hrs). The decrease in strength was less than 2 Ksi for all samples, so the data are not tabulated. It was concluded, therefore, that, even with a large furnace load of sheets for mill annealing, a cycle of 1450F (8 hrs) would not cause any appreciable strength loss compared to a lighter furnace load.

An investigation of the effect of hydrogen on the tensile and creep-stability properties of Ti-8Al-1Mo-1V sheet was initiated. This study is being made in the two annealed conditions. Mill annealed (1450 - 8 hrs) and duplex annealed (1800/1850F - 5min - AC + 1100F - 8 hrs), to establish the hydrogen tolerance for each. Until such a tolerance has been determined, a maximum hydrogen level of 150 ppm will be maintained.

PROCESSING OF Ti-8Al-1Mo-1V SHEET

The 92 sheet bars, representing the balance of material from the five 1600-pound ingots (V1551 - V1555) and which had been rolled to an intermediate stage in the last report period(1), were finish rolled from 1800F, descaled, and held for mill annealing until the laboratory annealing studies were completed (as described in the previous section). Earlier work had indicated that good creep properties could be achieved in sheets finish rolled from 1800F by proper choice of annealing temperature and time; therefore, there appeared to be no valid reason for changing the previously-established optimum finish rolling temperature of 1800F. These 92 sheets will be mill annealed at 1450F (8 hrs) during the next period. A tabulation of the number of sheets in process and the general status of processing is shown below.

Status of Ti-8Al-1Mo-1V Sheets

Gage, in	Number of Sheets Ordered	Number of Sheets in Process	Number of Sheets Completed
0.020	27	33*	9*
0.040	20	33*	9*
0.062	18	22*	6*
0.090	15	20*	6*
0.125	14	14	0

(*) Includes a total of 30 sheets as a pilot group which were mill annealed at 1450F (4 hrs) and which possess sub-standard 1000F creep properties

As the 30 pilot sheets of Ti-8Al-1Mo-1V referred to above had been mill annealed at 1450F (4 hrs) and the resultant creep properties were inferior to those originally obtained using the same annealing cycle in the laboratory, serious consideration is being given to removing these 30 sheets from the Titanium Sheet Rolling Program and replacing them with material from another 1700-pound ingot of Ti-8Al-1Mo-1V. This is deemed necessary, since the remaining sheets from V1551- V1555 will be mill annealed for 8 hours at 1450F and all sheets in the production phase of the contract should receive the same annealing cycle. A final decision to remove these 30 sheets from the program will be made early in the next report period.

PROPERTIES OF Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr SHEETS

As described in the previous report [1], preliminary tensile and bend properties were obtained in the evaluation of the initial sheets of the two alloys which indicated that lower finish rolling temperatures of 1750 - 1800F were preferable and that simple annealing at 1450 - 1750F provided good ductility although the strength levels were relatively low. Considerably more testing was performed in this period, including notch and standard tensile tests at several temperatures and creep-stability tests at 1000F in an effort to establish the optimum rolling and annealing cycles. Results of this additional evaluation are discussed in the following sections.

Notch and Standard Tensile Properties at Various Temperatures

The 0.062in sheet of each alloy finish rolled from each of the three temperatures, 1750, 1800, and 1850F, was used to determine the effect of rolling temperature on 800 and 1000F tensile properties and room temperature and -65F notch tensile properties. Both mill annealed (1350F - 8 hrs) and 1650F (1/2 hr) AC specimens were used for this phase of the investigation with the results shown in Tables 4 and 5.

Properties of Ti-5Al-5Sn-5Zr in Table 4 show that mill annealed sheet (1350F - 8 hrs) possessed higher -65F and room-temperature

TABLE 4 NOTCH AND STANDARD TENSILE PROPERTIES OF 0.062in Ti-5Al-5Sn-5Zr SHEETS AT VARIOUS TEMPERATURES (V-1540, Averages of Duplicate Longitudinal Tests)

Condition	Test Temp. F	UTS, Ksi	YS(0.2%), Ksi	Elong (2"), %	Notch Properties * K_t	NTS, Ksi	NSR
Sheet A-4801, Finish Rolled from 1750F -							
Mill Annealed	-65	143.8	138.7	23.8	3.0	179.1	1.24
(1350F - 8 hrs)	-65	-	-	-	6.0	167.0	1.16
	RT	126.7	123.1	19.0	3.0	163.4	1.29
	RT	-	-	-	6.0	157.7	1.24
	800	91.6	72.2	22.0	-	-	-
	1000	84.5	61.8	23.8	-	-	-
1650F (1/2 hr) AC	-65	140.2	126.3	15.0	3.0	172.9	1.23
	-65	-	-	-	6.0	170.7	1.22
	RT	124.4	112.8	15.3	3.0	160.0	1.28
	RT	-	-	-	6.0	156.0	1.25
	800	85.0	62.8	24.5	-	-	-
	1000	82.5	61.8	23.5	-	-	-
Sheet A-4804, Finish Rolled from 1800F -							
Mill Annealed	-65	143.6	136.3	17.5	3.0	173.5	1.21
(1350F - 8 hrs)	-65	-	-	-	6.0	162.3	1.13
	RT	128.7	122.8	18.3	3.0	161.5	1.26
	RT	-	-	-	6.0	147.3	1.15
	800	90.9	72.0	20.0	-	-	-
	1000	83.5	62.4	17.0	-	-	-
1650F (1/2 hr) AC	-65	139.8	125.4	14.5	3.0	166.3	1.19
	-65	-	-	-	6.0	164.3	1.18
	RT	123.9	111.0	16.0	3.0	154.8	1.25
	RT	-	-	-	6.0	149.1	1.20
	800	84.7	61.6	21.5	-	-	-
	1000	81.9	60.0	20.3	-	-	-

TABLE 4 (continued)

Condition	Test Temp, F	UTS, Ksi	YS(0.2%), Ksi	Elong(2"), %	Notch Properties * K_t	NTS, Ksi	NSR
Sheet A-4803, Finish Rolled from 1850F -							
Mill Annealed	-65	145.8	136.8	13.8	3.0	168.7	1.16
(1350F - 8 hrs)	-65	-	-	-	6.0	161.7	1.11
	RT	129.7	122.2	15.3	3.0	155.8	1.20
	RT	-	-	-	6.0	146.3	1.13
	800	91.1	72.3	18.0	-	-	-
	1000	83.6	66.3	14.5	-	-	-
1650F (1/2 hr) AC	-65	140.5	127.2	11.7	3.0	162.2	1.15
	-65	-	-	-	6.0	158.5	1.13
	RT	122.9	112.0	15.0	3.0	150.4	1.22
	RT	-	-	-	6.0	142.0	1.16
	800	81.6	61.2	22.5	-	-	-
	1000	77.5	58.5	20.3	-	-	-

(*) Notch Specimen - 0.500" gage width, 0.250" notch width.
for K_t = 3.0, notch radius = 0.020"
for K_t = 6.0, " " = 0.005"

NTS - Notch Tensile Strength
NSR - Notch - Unnotch Strength Ratio

TABLE 5 NOTCH AND STANDARD TENSILE PROPERTIES OF 0.062in Ti-7Al-12Zr SHEETS AT VARIOUS TEMPERATURES (V-1541, Averages of Duplicate Longitudinal Tests)

Condition	Test Temp, F	UTS Ksi	YS(0.2%), Ksi	Elong (2") %	Notch Properties * Kt	NTS, Ksi	NSR
Sheet A-4802, Finish Rolled from 1750F -							
Mill Annealed	-65	166.5	160.2	11.0	3.0	209.8	1.26
(1350F - 8 hrs)	-65	-	-	-	6.0	187.4	1.13
	RT	149.7	143.7	13.8	3.0	189.5	1.27
	RT	-	-	-	6.0	163.4	1.09
	800	114.5	98.0	17.0	-	-	-
	1000	105.3	82.0	19.8	-	-	-
1650F (1/2 hr) AC	-65	149.9	136.7	13.3	3.0	193.9	1.29
	-65	-	-	-	6.0	184.0	1.23
	RT	132.6	124.6	16.5	3.0	180.6	1.36
	RT	-	-	-	6.0	171.3	1.29
	800	93.1	77.9	23.0	-	-	-
	1000	86.0	74.3	24.5	-	-	-
Sheet A-4799, Finish Rolled from 1800F -							
Mill Annealed	-65	164.5	154.6	13.0	3.0	198.7	1.21
	-65	-	-	-	6.0	175.6	1.07
	RT	145.8	139.7	18.5	3.0	183.7	1.26
	RT	-	-	-	6.0	168.6	1.16
	800	111.8	94.0	21.5	-	-	-
	1000	102.0	75.0	21.0	-	-	-
1650F (1/2 hr) AC	-65	155.5	140.0	10.5	3.0	184.7	1.19
	-65	-	-	-	6.0	175.5	1.13
	RT	140.3	126.7	13.3	3.0	174.5	1.24
	RT	-	-	-	6.0	169.4	1.21
	800	100.6	78.0	25.5	-	-	-
	1000	94.0	74.5	19.5	-	-	-

TABLE 5 (continued)

Condition	Test Temp, F	UTS, Ksi	YS(0.2%), Ksi	Elong (2"), %	Notch Properties* Kt	NTS, Ksi	NSR
Sheet A-4800, Finish Rolled from 1850F -							
Mill Annealed	-65	159.8	148.3	6.0[(1)]	3.0	186.4	1.17
(1350F - 8 hrs)	-65	-	-	-	6.0	161.4	1.01
	RT	143.1	134.2	15.8	3.0	171.3	1.20
	RT	-	-	-	6.0	152.3	1.07
	800	104.9	88.6	17.5	-	-	-
	1000	99.5	80.4	13.8	-	-	-
1650F (1/2 hr) AC	-65	152.2	136.5	11.0	3.0	176.2	1.16
	-65	-	-	-	6.0	168.8	1.11
	RT	137.3	126.2	14.8	3.0	165.3	1.20
	RT	-	-	-	6.0	151.3	1.10
	800	93.5	73.2	24.0	-	-	-
	1000	88.8	69.6	21.5	-	-	-

(*) Notch Specimen - 0.500" gage width, 0.250" notch width
For K_t = 3.0, notch radius = 0.020"
For K_t = 6.0, " " = 0.005"

NTS - Notch Tensile Strength
NSR - Notch-Unnotch Strength Ratio

(1) Broke at end of gage length.

strengths than material subsequently annealed at 1650F (1/2 hr) AC, and that this strength advantage was also maintained at 800F. However, at 1000F the strength of both annealed conditions was about the same. The exception was sheet rolled from 1850F, in which the mill annealed strength advantage was still present at 1000F. Material rolled from 1750F exhibited more ductility at all testing temperatures and provided about the same strengths as 1800 and 1850F rolled sheets at -65F and room temperature. However, at 800 and 1000F, some strength advantage was indicated for material finish rolled from 1750F. Notch strengths and the notch strength ratio were higher for the 1750F rolled sheet; the notch properties gradually deteriorated with increased rolling temperature. On the basis of notch strength ratio and a theoretical stress concentration factor of Kt=6.0, specimens annealed at 1650F (1/2 hr) AC possessed better notch properties than those tested as mill annealed.

Therefore, on the basis of standard tensile properties and sub-zero temperature notch characteristics, it is concluded that, of the three, 1750F is the best finish rolling temperature. Notch properties also indicate that 1650F (1/2 hr) AC is a better annealing treatment than the 1350F mill anneal, although creep-stability properties will dictate, to a large extent, which finish annealing cycle should be used (see the next section).

Results of tensile tests on the three sheets of Ti-7Al-12Zr in Table 5 show, as would be expected, that mill annealed (1350F - 8 hrs) material maintains a strength advantage over 1650F (1/2 hr) AC annealed sheets at all test temperatures, although at 1000F the difference was not as well defined. For mill annealed samples, the yield strength at all testing temperatures decreased as the rolling temperature was raised from 1750 to 1850F. Mill annealed tensile elongation was greater at all test temperatures for the sheet finish rolled from 1800F. After annealing at 1650F (1/2 hr) AC, the ductility at -65F and room temperature was higher for 1750F rolled material, but at 800 and 1000F the differences among the three sheets were minor. Also, little difference in strength at the various test-

ing temperatures was observed among the three sheets after annealing at 1650F (1/2 hr) AC, although the strength of 1750F rolled material was slightly lower at room temperature and -65F than the sheet rolled from 1800F. Lower strengths were also obtained at 800 and 1000F on 1850F rolled material given the 1650F anneal.

In the mill annealed condition the notch properties at -65F suffered as the rolling temperature increased. At room temperature, the notch strength and notch strength ratio were slightly higher for 1800F rolled sheet compared to the one rolled from 1750F, but both exhibited much better notch characteristics than material rolled from 1850F. After annealing at 1650F (1/2 hr) AC, the notch strength and ratio steadily decreased at room temperature and -65F as the rolling temperature was raised.

Although the one sheet rolled from 1800F did display some ductility and notch property advantages as mill annealed and slightly better strength at -65F and room temperature after annealing at 1650F, the differences were not appreciably great and, furthermore, the mill annealed ductility advantage disappeared after annealing at 1650F (1/2 hr) AC. Therefore, on the basis of the above comparison, it is concluded that the best finish rolling temperature is 1750F. However, a final decision on this, along with selection of an optimum finish annealing cycle, will be made after results of creep-stability tests are evaluated.

Creep-Stability Properties of Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr

Earlier studies performed by TMCA during the development of Ti-5Al-5Sn-5Zr had shown that annealing treatments high in the

alpha field (1600-1650F) provided the best creep resistance. At lower temperatures the material was incompletely annealed and at higher temperatures (above 1700-1725F) in the alpha-beta field substantially greater creep deformation was obtained. Using this approach as a guide for both Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr sheets, a creep-stability investigation was outlined whereby each of the 18 initial sheets [1] (three gages and three rolling temperatures) would be evaluated after annealing at 1650F (1/2 hr) AC. In addition, the 0.062in sheet of Ti-5Al-5Sn-5Zr rolled from 1750F and the 0.062in sheet of Ti-7Al-12Zr finish rolled from 1800F were used to investigate the effect of various annealing temperatures from 1350 - 1650F on the 1000F creep-stability properties. Where necessary, chemical analyses (particularly oxygen and hydrogen) were made on a sheet sample or test specimens and metallographic examination was also performed to supplement the other data.

Results of the creep-stability tests are listed in Tables 6 and 7. As shown in Table 6, there was no stability problem in Ti-5Al-5Sn-5Zr at any gage, annealing temperature, or finish rolling temperature investigated. One 0.020in specimen suffered some loss in elongation due to incidental stress corrosion, but, for the volume of samples tested, this indicated that either the alloy is not particularly sensitive to incidental salt contamination (incomplete cleaning or improper handling procedures) or that the laboratory techniques were extra meticulous. Based on the high level of stress corrosion obtained in Ti-7Al-12Zr (Table 7), which was tested during the same period, the former seems more probable.

Excellent 1000F creep resistance was achieved after annealing at 1650F (1/2 hr) AC with slightly less creep deformation being obtained in sheets rolled from the higher temperatures of 1800 and 1850F. The improvement in creep resistance with increased annealing temperature was clearly shown by the results attained from the 0.062in sheet rolled from 1750F. Partial chemical analyses are

TABLE 6 (continued)

Gage, in.	Sheet No.	Rolling Temp, F	Condition	Dir	Creep Def, %	UTS, Ksi	YS(0.2%), Ksi	Elong(1"), %
0.062	A-4804	1800	1650F (1/2 hr) AC	L	Not Exp.	121.0	108.7	17.5
(0.074% O_2.			"	L	0.000	122.9	106.9	20.0
37 ppm H_2)			"	T	Not Exp.	121.1	112.1	20.5
			"	T	0.017	124.0	114.0	19.0
0.062	A-4803	1850	1650F (1/2 hr) AC	L	Not Exp.	120.4	109.3	19.0
(0.078% O_2,			"	L	0.000	120.4	108.6	19.0
38 ppm H_2)			"	T	Not Exp.	121.6	110.8	18.0
			"	T	0.017	124.1	111.0	19.0
0.090	A-4814	1750	1650F (1/2 hr) AC	L	Not Exp.	122.1	111.8	20.0
(0.072% O_2,			"	L	0.048	122.1	109.9	21.0
30 ppm H_2)			"	T	Not Exp.	120.6	112.8	22.0
			"	T	0.039	120.7	113.2	21.0
0.090	A-4815	1800	1650F (1/2 hr) AC	L	Not Exp.	118.6	108.3	19.0
(0.096% O_2.			"	L	0.023	121.8	114.2	22.0
37 ppm H_2)			"	T	Not Exp.	120.6	109.5	20.5
			"	T	0.039	123.9	115.0	20.0
0.090	A-4813	1850	1650F (1/2 hr) AC	L	Not Exp.	124.3	113.1	16.0
(0.078% O_2,			"	L	0.040	125.5	117.0	17.0
41 ppm H_2)			"	T	Not Exp.	128.2	116.8	17.0
			"	T	0.017	130.1	118.4	11.0 (4)

(*) All creep-stability specimens tensile tested at room temperature after creep exposure without surface pickling or conditioning.
(1) Broke at end of gage length.
(2) Evidence of incidental stress corrosion causing lowered elongation.
(3) Average of duplicate tests.
(4) Several parallel surface cracks in gage length; probably caused by insufficient acid pickling after 1650F (1/2 hr) AC anneal.

TABLE 7 CREEP-STABILITY PROPERTIES OF Ti-7Al-12Zr SHEETS*
(V-1541, Rolled as indicated, mill annealed 1350F - 8 hrs, and laboratory annealed as shown; Creep Exposure 1000F - 25 Ksi - 150 hrs)

Gage, in	Sheet No.	Rolling Temp, F	Condition	Dir	Creep Def, %	UTS, Ksi	YS(0.2%), Ksi	Elong, (1") %	
0.020	A-4798	1750	1650F (1/2 hr) AC	L	Not Exp.	136.2	128.0	15	(1)
(0.109% O_2,			"	L	0.07	116.6	Broke short	0	(1, 2)
78-90 ppm H_2)			"	T	Not Exp.	130.8	124.4	16.5	
			"	T	0.021	133.1	128.0	6	(1)
0.020	A-4811	1800	1650F (1/2 hr) AC	L	Not Exp.	133.0	125.0	19	
(0.089% O_2,			"	L	0.057	136.8	128.9	11	(1, 2)
57 ppm H_2)			"	T	Not Exp.	131.8	122.7	19	
			"	T	0.082	131.0	128.8	2	(2)
0.020	A-4805	1850	1650F (1/2 hr) AC	L	Not Exp.	127.5	111.1	9	(1)
(0.084% O_2,			"	L	0.031	134.2	111.5	2	(1, 2)
53 ppm H_2)			"	T	Not Exp.	130.0	118.7	16	
			"	T	0.068	129.5	123.1	2.5	(1, 2)
0.062	A-4802	1750F	1650F (1/2 hr) AC	L	Not Exp.	128.1	121.6	20	
(0.091% O_2,			"	L	0.040	131.2	109.5	15	(1)
35-41 ppm H_2			"	T	Not Exp.	124.7	121.9	22	
6.98% Al			"	T	0.056	126.3	116.9	5	(1, 2)
11.59% Zr									
0.05% Fe									
0.008% C									
0.008% N_2)									

(continued on Sheet 2)

TABLE 7

Gage, in	Sheet No.	Rolling Temp, F	Condition	Dir	Creep Def, %	UTS Ksi	YS(0.2%), Ksi	Elong (1"), %
0.062	A-4799	1800	As Mill Annealed	L(3)	Not Exp.	145.8	137.1	21.0
(0.086% O_2			(1350F - 8 hrs)	L(3)	0.25	141.3	127.9	5.0 (2)
40-55 ppm H_2			"	T	Not Exp.	142.7	135.3	20.0
6.98% Al			"	T	0.23	144.4	134.1	9.0 (2)
11.17% Zr			1450F (2 hrs) AC	L	Not Exp.	141.8	132.4	20.5
0.05% Fe			"	L	0.19	143.5	121.4	21.0
0.016% C			"	L	0.17	143.4	131.8	9.0 (2)
0.012% N_2)			"	T	Not Exp.	136.3	128.3	21.0
			"	T(3)	0.16	138.9	133.7	2.0 (1, 2)
			1550F (1 hr) AC	L	Not Exp.	138.8	129.0	21.0
			"	L	0.10	143.1	132.9	20.0
			"	L	0.10	142.0	123.3	11.0 (2)
			"	T	Not Exp.	135.8	127.7	19.0
			"	T(3)	0.14	138.5	119.4	15.0
			1650F (1/2 hr) AC	L	Not Exp.	135.1	125.2	20.0
			"	L	0.09	136.3	122.9	3.5 (1, 2)
			"	L	0.048	139.6	122.4	9.0 (1, 2)
			"	T	Not Exp.	133.4	124.5	21.0
			"	T(3)	0.07	136.0	124.5	6.0(2)
0.062	A-4800	1850	1650F (1/2 hr) AC	L	Not Exp.	133.8	120.6	20.0
(0.089% O_2			"	L	0.018	134.1	115.3	7.0 (2)
46 ppm H_2			"	T	Not Exp.	129.3	117.6	20.0
6.92% Al			"	T	0.046	132.4	123.4	3.0 (2)
11.58% Zr								
0.05% Fe								
0.008% C								
0.009% N_2)								

(continued on Sheet 3)

TABLE 7

Gage, in	Sheet No.	Rolling Temp, F	Condition	Dir	Creep Def, %	UTS, Ksi	YS(0.2%), Ksi	Elong (1"), %
0.090 (0.073% O_2, 32-40 ppm H_2)	A-4809	1750	1650F (1/2 hr) AC	L	Not Exp.	133.3	120.3	20.5
			"	L	0.038	115.5	Broke short	0 (2)
			"	T	Not Exp.	129.2	117.6	21.5
			"	T	0.021	132.1	120.5	2 (1, 2)
0.090 (0.073% O_2, 23-37 ppm H_2)	A-4808	1800	1650F (1/2 hr) AC	L	Not Exp.	132.4	121.4	21
			"	L	0.09	131.5	112.7	2 (2)
			"	T	Not Exp	131.8	121.9	21
			"	T	0.065	138.8	129.2	11 (2)
0.090 (0.077% O_2 47 ppm H_2)	A-4810	1850	1650F (1/2 hr) AC	L	Not Exp.	131.2	118.6	20
			"	L	0.031	131.1	121.0	3 (2)
			"	T	Not Exp.	132.4	119.9	20
			"	T	0.040	136.9	123.8	4 (2)

(*) All creep-stability specimens tensile tested at room temperature after creep exposure without surface pickling or conditioning.

(1) Broke at end of gage length.

(2) Evidence of incidental stress corrosion causing lowered elongation or brittle fracture.

(3) Average of duplicate tests.

also included in Table 6; all oxygen and hydrogen levels were below 0. 10 percent and 60 ppm, respectively.

As the creep resistance of sheet rolled from 1750F was only slightly less than in material rolled from the two higher temperatures, and, from a previous section of this report, the notch properties of 1750F rolled sheet were better, an optimum finish rolling temperature of 1750F is recommended for Ti-5Al-5Sn-5Zr. A final annealing cycle of 1650F (1/2 hr) AC also appears to be the best from the standpoint of creep resistance, without undue sacrifice of strength, but a final decision on annealing will be deferred until additional creep-stability properties are performed using shorter times at 1650F and simulated mill annealing cycles at 1400-1500F. These additional studies, including metallographic examination, will be initiated during the next report period.

In contrast to the excellent stability exhibited by Ti-5Al-5Sn-5Zr (Table 6), the measurement of stability of Ti-7Al-12Zr sheet in Table 7 was generally masked by the preponderance of incidental stress corrosion cracking. As indicated previously in this section of the report, the specimens from both alloys were processed through the creep testing laboratory about the same time (within a 2 or 3-week period) and, therefore, the specimen cleaning and handling procedures were judged to be very nearly the same. If this is so, then it appears that Ti-7Al-12Zr must be cleaned and handled far more carefully than Ti-5Al-5Sn-5Zr before creep exposure at 1000F.

The loss of elongation of the Ti-7Al-12Zr specimens, which had suffered stress corrosion damage, was a direct function of the severity of such stress corrosion (depth of crack as indicated by low magnification observation of the tensile fractures). All of the creep-stability samples listed in Table 7 were examined for evidence of stress corrosion as a foundation for the statement above. However, no evidence of stress corrosion was observed in some of the specimens in Table 7, and, therefore, unless noted to the contrary, stress corrosion was not established as the reason for poor elongation. In such cases where the ductility had deteriorated with no evidence of stress corrosion, it is concluded that the specimens were unstable. This instability could be metallurgical or structural in nature or it could be due to a surface phenomenon, such as oxygen enrichment, hydrogen enrichment, type of surface before creep exposure, et cetera . Since none of these samples was acid pickled after exposure,

it is not known whether the instability is due to metallurgical reactions or to a surface reaction. As an estimate, it seems probable that acid pickling after creep exposure would have improved the elongation, but perhaps not to the original starting level. The fact that, in many instances, the strength increased 5-10 Ksi after exposure would indicate the existence of some metallurgical reaction at 1000F for 150 hours. Partial chemical analyses are included in Table 7; except for the 0.020in sheet rolled from 1750F, all oxygen values were 0.09 percent or less. This same sheet also contained 78 - 90 ppm hydrogen; all others were at a level lower than 60 ppm.

Somehwat better stability was exhibited by 1750 and 1800F rolled material than sheets rolled from 1850F. Generally, the best creep resistance was achieved in sheets rolled from 1750 and 1850F. Therefore, in view of the improved notch properties obtained in material rolled from 1750F (see the previous section, Table 5), an optimum finish rolling temperature of 1750F is recommended for Ti-7Al-12Zr. Selection of a final annealing temperature cannot be made at this time because of the stress corrosion -stability question, although the best creep resistance is offered by annealing at 1650F. Additional creep-stability tests will be performed, utilizing even more care in specimen cleaning and handling to minimize the incidental stress corrosion problem. Simulated mill annealing temperatures of 1400-1500F, specimens of 1750 and 1800F rolled sheet simple annealed at 1450 - 1750F, and longer times at 1650F will be investigated (with and without acid pickling after creep exposure) to determine the optimum annealing cycle. These additional studies, including thorough metallographic examination, will be initiated during the next report period.

An investigation of the welded properties of the two alloys will also be undertaken during the next period and will include notch and standard tensile, bend, and creep-stability tests on as-welded, welded-and-stress relieved, and welded-and-annealed material. A previously-outlined study of the effect of hydrogen on the tensile and creep-stability properties of Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr sheet will also be in progress utilizing both a simple alpha anneal (1650F) and a simulated mill anneal (1450F - FC) as two extremes in annealing regarding the presence of a possible precipitated second phase in the microstructure.

PROCESSING OF Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr SHEET

With an optimum finish rolling temperature of 1750F having been established for both alpha alloys, the balance of the 2-7/8 x 12in slab material from the two initial heats was scheduled for rolling to 36 x 96in sheets as follows:

Gage, in	No. of Sheets	Heat and Position
Ti-5Al-5Sn-5Zr -		
0.020	4	V 1540 B
0.062	4	V 1540 B
0.090	4	V 1540 T
Ti-7Al-12Zr -		
0.020	6	V 1541 B
0.062	7	V 1541 T
0.090	4	V 1541 B

Sheet bars were cut and two-stage cross rolled to intermediate size without serious difficulty from 1850 - 1870F. However, it was observed that the corners of the bars started to shear crack when the surface temperature had dropped to about 1600 - 1625F. Because of this phenomenon, which limits the extent of rolling after a single heating operation, an additional reheat would be required for some sizes of bars. To minimize the need for this extra reheat, future bars of both alloys will be rolled to the intermediate stage from a slightly higher temperature of 1880-1900F.

All of the intermediate rolled bars were descaled, pickled, conditioned, and vacuum annealed at 1350F to reduce the hydrogen content to less than 50 ppm. In the next period they will be finish rolled from 1750F to complete the three stages of cross rolling, descaled, mill annealed at 1350F (8 hrs), and rough ground. Processing will then be interrupted until the optimum finish annealing cycle has been established, based on additional laboratory studies to be performed during the next report period.

At this stage in the contract, it was felt that sheet processing experience and laboratory investigations had progressed sufficiently on Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr to permit acquisition of ingots for Item 2, the production phase of NOas 59-6227-c. As listed in the Sixth Bimonthly Report[2], 2000 pounds of finished sheet of five gages are to be produced from each alloy. Therefore, three 1700-pound ingots of each composition were scheduled for melting during the next period. This schedule provides only a nominal quantity of sheet in excess of the ordered weight; consequently, if as processing of these six heats progresses and a need is indicated for additional stock, more ingots can be melted at that time.

FUTURE WORK

Ti-8Al-1Mo-1V

Item 1

The investigation of the effect of hydrogen on tensile and creep-stability properties will be continued in a program to establish a maximum tolerable hydrogen level for Ti-8Al-1Mo-1V sheet. Additional evaluation of the creep-stability properties at various temperatures (800 - 1100F) and sub-zero temperature notch tensile characteristics will be initiated on sheet mill annealed at 1450F and duplex annealed at 1800/1850F (5 min) AC + 1100F (8 hrs).

Item 2

The 92 rolled sheets from V1551 - V1555 will be mill annealed at 1450F (8 hrs) during the next period and finishing procedures continued. A final decision will be made to remove from the program the 30 earlier sheets which had been mill annealed at 1450F (4 hrs) and possessed sub-standard 1000F creep properties. If removed, these sheets will be replaced by material from another 1700-pound ingot of Ti-8Al-1Mo-1V.

Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr

Item 1

Additional creep-stability properties will be obtained on the initial sheets of both alloys to determine the optimum finish annealing temperature for each. An investigation of welded properties of the two compositions will be conducted and the study of the effect of hydrogen on the tensile and creep-stability properties will also be continued.

The balance of material from the first two heats, one each of Ti-5Al-5Sn-5Zr and Ti-7Al-12Zr, which has been rolled to an intermediate stage, will be finish rolled from 1750F. As soon as the optimum finish annealing cycle has been established, the sheets will be final annealed, ground, pickled, and tested.

Item 2

Three 1700-pound ingots of each of the two alloys will be melted and processing procedures and conditions will be formulated to produce 2000 pounds of finished sheet from each composition.

DLDay/ab

REFERENCES

1) Eighth Bimonthly Report, Titanium Sheet Rolling Program for Ti-8Al-1Mo-1V, Ti-5Al-5Sn-5Zr, and Ti-7Al-12Zr, Navy Bureau of Aeronautics' Contract NOas 59-6227-c, Titanium Metals Corporation of America, 30 June 1961.

2) Sixth Bimonthly Report, Titanium Sheet Rolling Program for Ti-8Al-1Mo-1V, Ti-5Al-5Sn-5Zr, and Ti-7Al-12Zr, Navy Bureau of Aeronautics' Contract NOas 59-6227-c, Titanium Metals Corporation of America, 30 March 1961.
